Evaluate The Robustness and Progressive Crushing Of Crush-Boxes In Crash Simulation Of an F1 Racing Car In Frontal Impact

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Abstract - *This paper presents the crash analysis of F1 car in frontal impact. F1 cars are subjected to high-speed and having high possibilities of crash either themselves or hitting the barrier. Therefore in order to ensure the driver safety in frontal impact, special impact structure such as nose cone is designed to absorb the race car kinetic energy to reduce the decelerations acting on the human body. In this study an attempt has been made that the nose structure is modified by inserting some aluminium crush-boxes in it. Thus it can absorb more energy, reduce deceleration forces and driver will be safe inside the survival cell. Here two FE models are developed one with crush-boxes and other without crush-boxes in the nose structure using Hypermesh V11 tool. Crash simulation of both the models is carried out using LS-DYNA and results are plotted in LS-Prepost. The results obtained for structure with crush-boxes and without crush-boxes are compared and validate with the standard FIA regulations. Finally in conclusion, the results obtained for modified model are better and closer to the standard regulations.*

Key Words: F1 car, Crash simulation in frontal impact, Aluminium crush-boxes, LS-DYNA.

1. INTRODUCTION

Formula one car is an automobile designed just to race at high speeds on circuits or closed courses. It is the top class of motorsports which shows the driving execution of race cars at high speeds, this outcomes advancement in the zone of lightweight materials and aerodynamic design. Since racing a car includes high speed which may leads to sever accidents. Thus special measures are taken for the driver's safety in case of high speed crashes. Other than the driver's protective equipment like helmet, head and neck supports and the circuit's safety like run-off areas or barriers, the F1 car itself is designed for crashworthiness and has unique impact structures, which absorb the race car's kinetic energy and limit the deceleration forces acting on the human body. The FIA (Federation of International Automobile) sets strict regulations for the performance of these energy absorbing structures and is updated for each racing season. The main reason behind these regulations is to assure that the driver must be enclosed within a strong survival cell, surrounded by energy absorbing structures in the front, side and back. Each F1 racing car must withstand static tests (nose push-off test, side intrusion test etc.) and dynamic tests (frontal impact, rear impact, side impact and steering column test). These tests are carried out according to FIA test procedure in the presence of an FIA technical delegate.

Fig -1: F1 racing car

2. METHODOLOGY

In the present work the CAD model of front structure of F1 car is developed in SOLIDWORKS and the FE model with and without aluminium crush-boxes are developed using Hypermesh. Then crash simulation will be carried out in LS-DYNA according to FIA regulations. The simulation results obtained for baseline structure (without crush-boxes) and modified structure (with crush-boxes) are compared. Validation can be made with the standard FIA regulations mentioned for the frontal impact structures. Finally the conclusion will be done depends on comparison of result and validation.

3. FRONTAL IMPACT TESTING STANDARDS

All tests must be carried out in accordance with FIA Test Procedure, in the presence of an FIA technical delegate. FIA aims to assure that the nose structure is able to dissipate the kinetic energy involved in the crash and driver is protected from injurious deceleration forces. They demand a total weight of 780kg and an impact velocity of 15m/s. when the test structure strikes on rigid immovable wall, its resistance must be such that the peak deceleration over the first 100mm of deformation may not exceed 10g, the peak deceleration over the first 60kJ energy absorption does not exceed 20g and the average deceleration of the test structure may not exceed 40g.

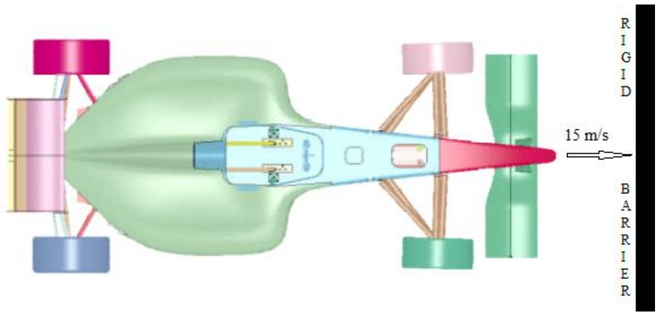

Fig -2: Frontal impact

4. MODEL DEVELOPMENT

4.1 Geometric model

To carry out CAE analysis of any component, the solid model of the same is essential. Here the CAD model of front structure of F1 car is modeled using SOLIDWORKS tool and saved in .step format. The front structure of F1 car consists of components such as nose structure, chassis (survival cell), front wing, wing pillars, front axle assembly and front wheels. The assembled CAD model is shown in Fig-3.

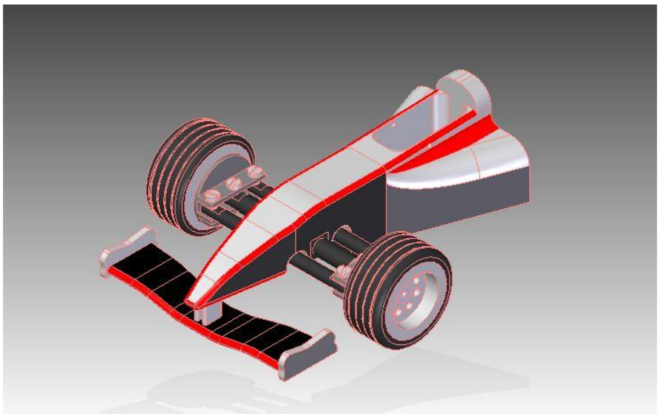

Fig -3: CAD model

4.2 Meshed model

For meshing the CAD model is imported to Hypermesh in .step format. Meshing is carried out using shell and solid elements. Nose structure, survival cell and front wing are meshed using shell quad4 elements with an average element size of 8mm. For quality mesh Tria3 elements are also allowed in the shell meshing. Axle radachse, screw, bolts, wheel bolts, hub, tyres and mac-wheel are meshed using solid tetra4 elements with average element size 8mm. In order for good results quality checks are made. Fig-4 shows the meshed model of front structure of F1 car consists of 445738 total number elements in that 42494 elements are shell qua4, 403244 elements are solid tetra4.

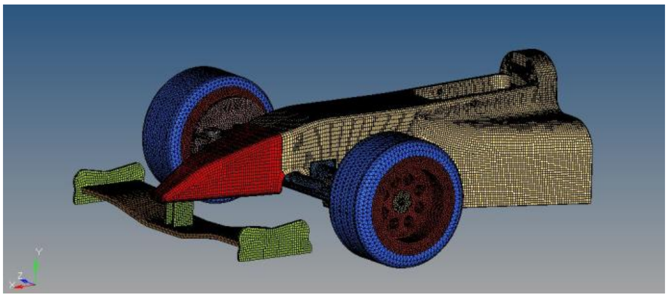

Fig -4: Meshed model

4.3 Materials and Properties

The impact structures are generally made of carbon fibers which are impregnated with resin, and the structure is manually laminated, for providing effective energy absorbing properties to it. In this simulation, the nose structure is made of carbon fiber. The survival cell, front wing and their attachments are made of Aluminium. Then, the whole axle assembly is consisting of steel and for tyres rubber material is assigned. In this simulation the axle assembly and wheels are considered as rigid bodies. The crush boxes are made of Aluminium. Table-1 shows the materials and properties.

Table -1: Materials and properties

Material	Properties	Value
Carbon Fiber	Density (ρ)	1.60g/cm3
	Modulus in direction 1 (E_1)	70GPa
	Modulus in direction 2 (E_2)	70GPa
	Shear modulus (G_{12})	5GPa
	Major Poisson's ratio (μ_{12})	0.10
	Minor Poisson's ratio (μ_{21})	0.02
	Compression strength in direction 1 (σ_{u1c})	600MPa
	Compression strength in direction 2 (σ_{u2c})	570MPa

Property	Aluminium	Steel (rigid)	Rubber
Young's Modulus (E) MPa	7.1e4	2.1e5	1700
Yield strength (s) MPa	170	----	250
Poisson's ratio (μ)	0.2	0.3	0.3
Density (ρ) g/cm3	2.2	7.89	1.6

In LS-DYNA materials are assigned to the components using material model (*MAT card). For carbon fiber MAT54 (*MAT_ENHANCED_COMPOSITE_DAMAGE) was used. For aluminum and rubber MAT24 (*MAT_PIECEWISE_LINEAR_PLASTICITY) was used and for rigid MAT20 (*MAT_RIGID) was used.

4.3 Nose structure

Nose structure without crush-boxes (baseline model) and structure with crush-boxes are shown in below figures.

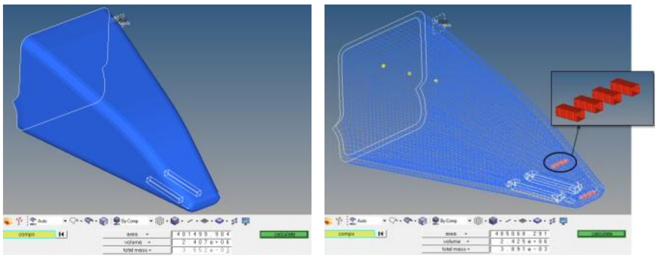

Fig -5: Nose structure of baseline and modified model.

Crush-boxes are made of aluminium material and of size 10mm X 10mm. In the nose section a parallel layer of surface is created and eight such crush-boxes are inserted between these two surfaces by using single surface contact. The weight of the structures are slightly varies.

4.4 Boundary conditions

The generated FE model is assigned with the total weight of 780kg including the minimum weight of dummy as 75kg. Next an initial velocity of 15m/s is ascribed to the whole structure which is free to translate only in X-direction and allowed to strike a rigid wall. Also in this simulation, axle assembly and wheels are considered as rigid. Fig-6 shows the boundary conditions for frontal impact.

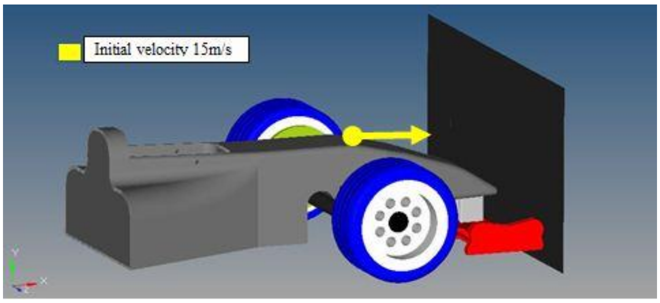

Fig -6: Boundary conditions

5. SIMULATIONS AND RESULTS

The FE model was generated by assigning material properties, contacts, boundary conditions and also proper control cards are used to carry out simulation in LS-DYNA. Then the results are plotted in LS-Prepost for baseline and modified model which are discussed below.

5.1 Results/Plots

- **Section forces**

A graph of cross sectional forces at nose section and at survival cell for baseline and modified model is shown in below figure. From which we can see section force for baseline model at nose section is 350kN and at survival cell is 30kN, similarly for modified model it is 420kN at nose and 50kN at survival cell.

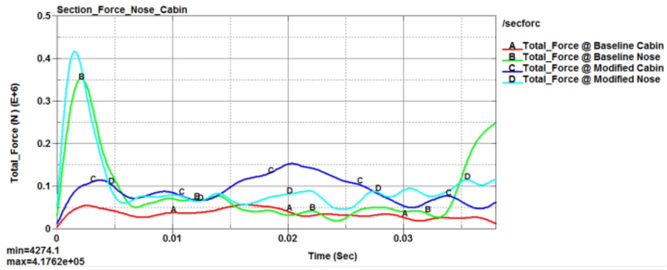

Fig -7: Section forces

- **Internal energy**

Below graph shows the internal energy in modified and baseline model. Internal energy is nothing but how much energy the particular component can be absorbed. From the graph we can see the internal energy for modified model is 95kJ and for baseline model is 71kJ.

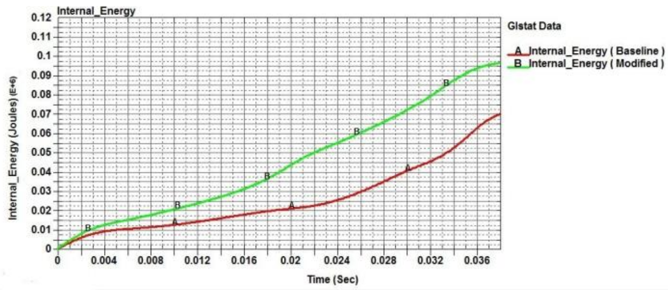

Fig -8: Section forces

- **Specific energy absorption (SEA)**

Specific energy absorption (SEA) is the efficiency of energy absorbed by a structure. It is defined as;

$$SEA = \frac{Total\ Energy\ absorbed\ (kJ)}{Mass\ (kg)}$$

In baseline model, the internal energy obtained is 71kJ and mass of the model is 787kg. Therefore,

$$SEA = \frac{71\ kJ}{787\ kg}$$

$$SEA = 0.0902\,\frac{kJ}{kg}$$

In modified model, the internal energy obtained is 95kJ and mass of model is 787.34kg. Therefore,

$$SEA = \frac{95\ kJ}{787.34\ kg}$$

$$SEA = 0.1206\,\frac{kJ}{kg}$$

- **Stress plots**

The stresses and strains are plotted at survival cell for baseline and modified model at two different times are shown below. For baseline model the maximum stress at time 0.00099sec is 376.7MPa and at time 0.039sec is 589.4MPa similarly for modified model stresses are 141.38MPa and 293.51MPa respectively.

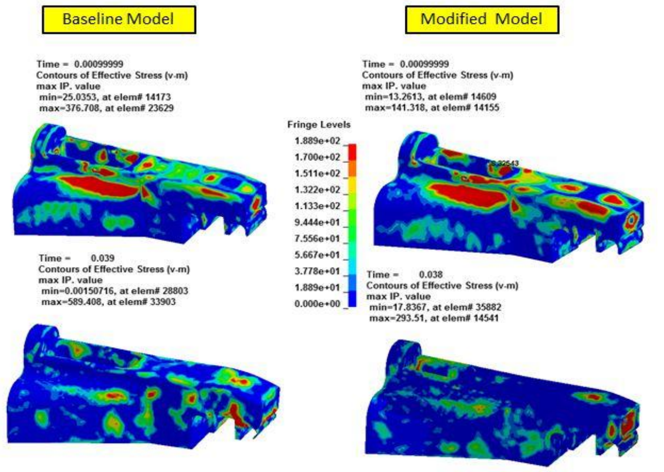

Fig -9: Stress plots

The percentage strain at survival cell for baseline model is 36.6% and for modified is 25.29%

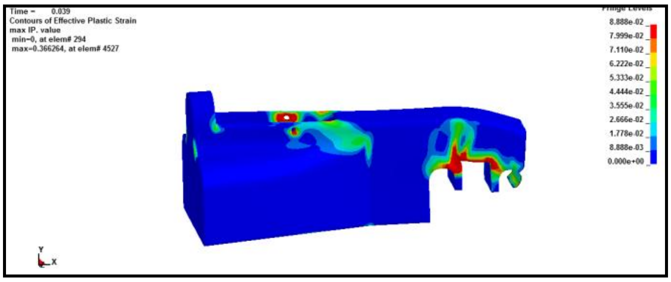

Fig -10: Strain plot of baseline model.

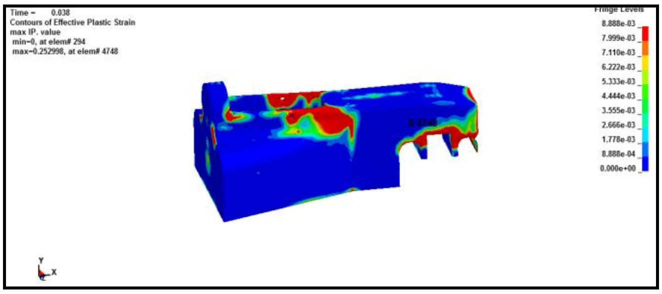

Fig -11: Strain plot of modified model.

- **Displacement graph**

From the displacement graph we can see for modified model at time 0.038sec displacement value is 380mm and for baseline model the displacement observed is 407mm.

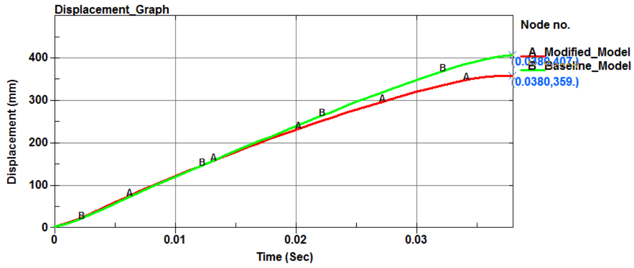

Fig -12: Displacement graph

- **Deceleration vs. Displacement graph**

A combined graph of deceleration vs. displacement for baseline, modified and standard curve is shown below. From the graph we can see peak deceleration for baseline model is 46g and in modified model it is 41g. For standard graph peak deceleration is 38g.

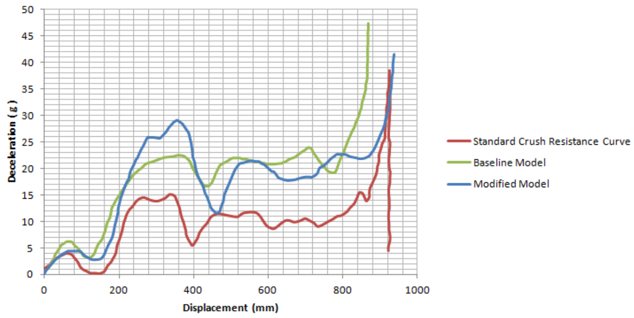

Fig -13: Deceleration vs. Displacement

5.2 Comparison of results

Table-2 shows the summary of results and comparisons between results can be seen.

Table -2: Summary of results

Plot/Result Description		Baseline Model	Modified Model
Section Forces	At Nose section	350kN	420kN
	At Survival cell	30kN	50kN
Internal Energy		71kJ	95kJ
Specific Energy Absorption (SEA)		0.0902kJ/kg	0.1206kJ/kg
Stress (Survival cell)	At time 0.00099 sec	376.7MPa	141.38MPa
	At time 0.39 sec	589MPa	293.51MPa
Strain (Survival cell)		36.6%	25.29%
Displacement		407mm	380mm

6. VALIDATION

In this, validation can make by comparing the Deceleration vs. Displacement graph of test structure.

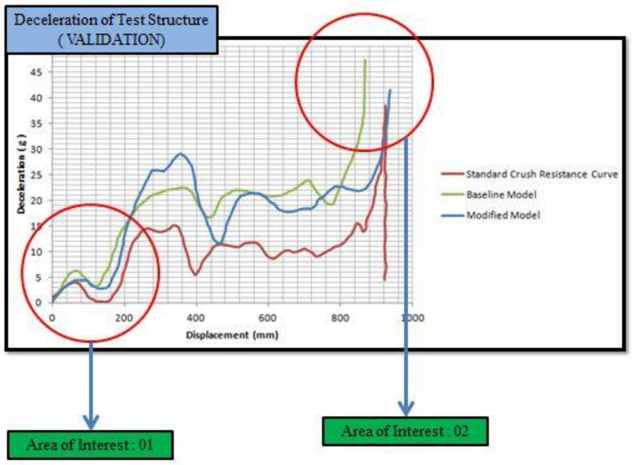

Fig -14: Deceleration of test structure.

In the above graph there are two area of interest for the purpose of validation.

Area of Interest 1: According to FIA regulation, during the frontal impact the resistance of the test structure must be such that the deceleration till 100mm of displacement does not exceed 10g. So from the above graph we can see for baseline structure till 100mm deceleration is 6g and for modified structure is 4.8g.

Area of Interest 2: According to FIA regulation standards, the average/peak deceleration of the test structure should not exceed 40g. From the graph we can see that the deceleration of baseline structure is 46g and modified structure is 41g where both the values are exceeding the standard value. But the deceleration of modified model is closer to standard value and it can be reduced by adding some more number of aluminum crush boxes in the nose structure or at the end of the nose structure.

7. CONCLUSION

From comparison of results and validation part we can conclude that the modified model with the introduction of crush-boxes in the nose section can give better results and validated with standard FIA regulations. Still deceleration acting on human body can be reduced by adding some more number of crush-boxes in the nose section.

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